Workshop on Instrumentation for Muon Cooling Studies

Illinois Institute of Technology, November 10-11, 2000

Prospects for a High Intensity Muon Facility at RAL

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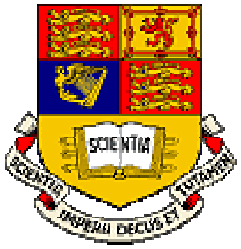
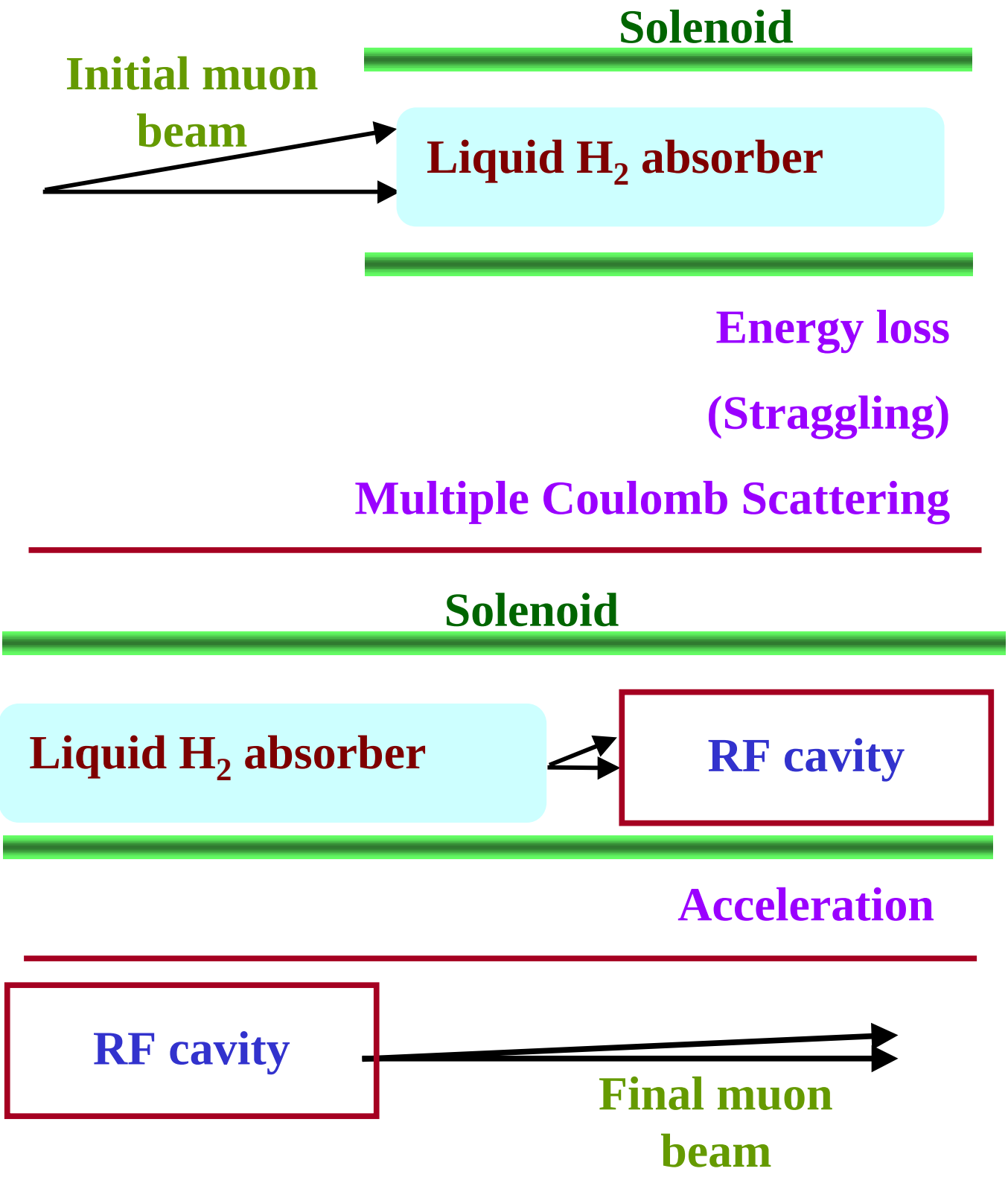


Contents

... a high intensity muon beam for R&D into the νFct front end

- **Beam instrumentation**
  - → **Very high flux beam**
  - → **Very low mass detectors**
- **μ-beams for νFct R&D at RAL**
  - → **Phase I: Cooling Demonstration in the HEP Test-Beam (an upgrade of MuScat?)**
  - → **Phase II: A high intensity bunched muon beam at RAL**

Instrumentation and the cooling channel



- Ionisation cooling of transverse emittance:

- **Ionisation cooling relies on energy loss to reduce beam momentum**
- **Multiple Coulomb scattering results in larger angular divergence as beam leaves absorber**
- **RF cavity restores longitudinal momentum**

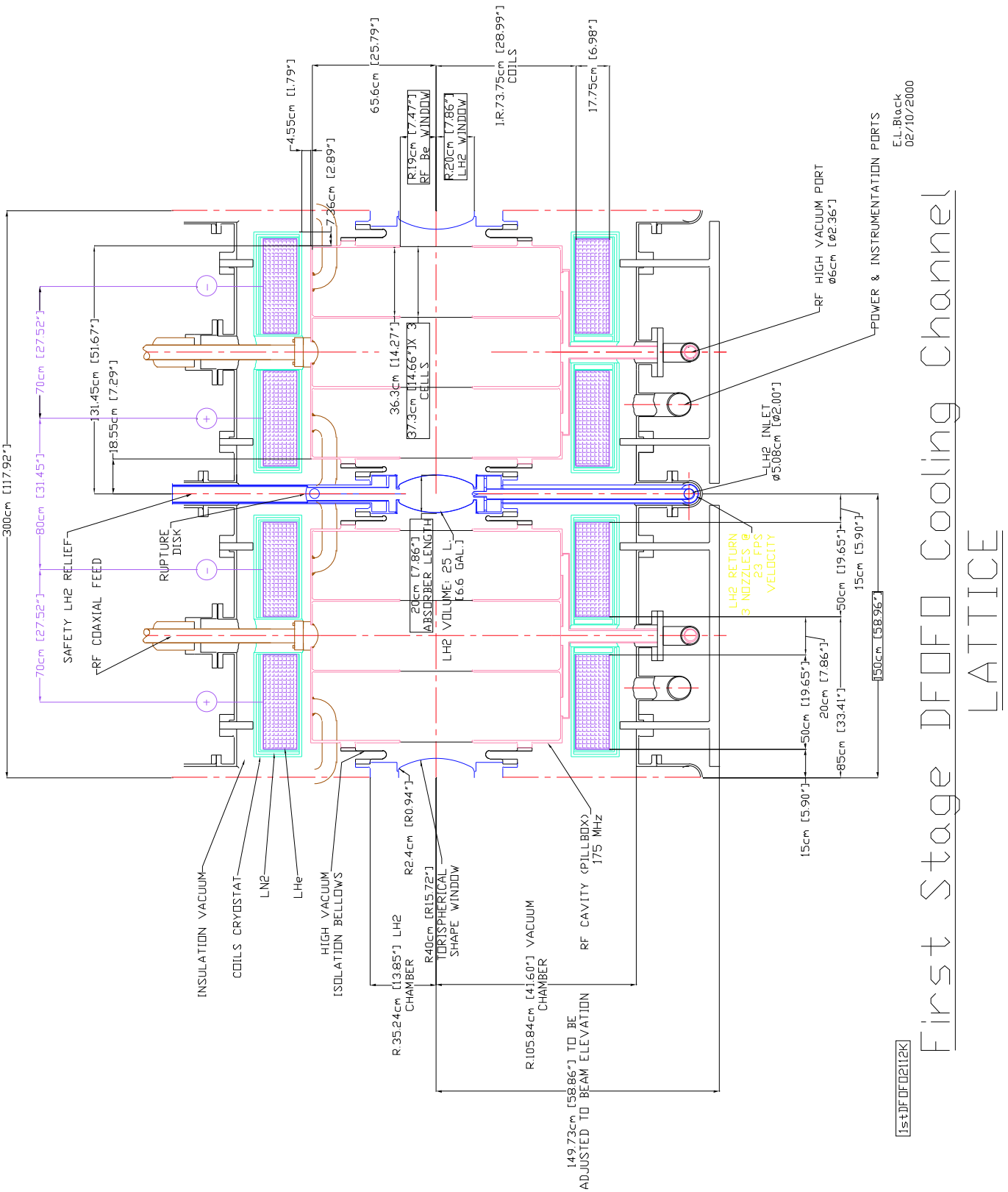
Cooling channel consists of repetition of absorber and RF cavity in confining solenoidal field

Ideal absorber for cooling channel has

- **Large X_0 and large dE/dx**
- **'Ratio' dE/dx to X_0 must allow cooling to 'beat' heating**

Liquid hydrogen proposed as X_0 vs dE/dx has been shown, in simulations, to cool

Instrumentation and the cooling channel



http://www.fnal.gov/projects/muon_collider/nu-factory/subsys/ss-cooling/nuss-cooling.html

- Brief outline of the challenge:

- **In FNAL design absorber is ~13 cm liquid hydrogen contained by 300 μm aluminium windows**

  $\Rightarrow$ L-H_2 $\rightarrow$ 1.5% X_0, windows 0.9% X_0

- **Instrumentation must exploit existing material or be *very* low mass. Must operate in presence of intense (dirty) muon beam and intense X-ray background from RF cavities.**
- **Cherenkov light from foils: Image of intense beam, excellent timing. Can it be done?**
- **Transition radiation from thin foil: Image of intense beam and good timing. Can light be collected?**
- **Development of feedback: e.g. must ensure that the RF cavities regenerate exactly the momentum lost in the absorbers.**

The νFct World Needs a High Intensity Muon Beam!

Two classes of issue:

Basic physics:

- **Important details of multiple Coulomb scattering, *dE/dx* of low energy muons in matter and straggling need to be measured (MuScat + upgrade)**

Cooling demonstration:

- **Even when the 'basic physics' measurements have been made and encorporated into simulations of the cooling channel it will be necessary to demonstrate that each piece of the cooling channel and its diagnostics and feedback systems work both individually and as a *SYSTEM*!**

Need to develop a 'phased' muon R&D facility

- **Phase I: Address basic physics issues**
- **Phase II: Develop elements of and instrumentation for cooling demonstration**

Muon beams for νFct R&D at RAL

Phase I: Basic Physics of Ionisation Cooling

Transverse emittance cooling:

$$\frac{1}{\varepsilon_{\perp,\mathrm{N}}}\frac{d\varepsilon_{\perp,\mathrm{N}}}{dz} = \frac{1}{\beta^2}\frac{1}{E}\left\lfloor \frac{dE}{dz} + \eta\frac{\left\langle x^2\right\rangle}{\varepsilon_{\perp,\mathrm{N}}^2}\frac{1}{X_0}\right\rfloor$$

Fight between *dE/dx* and multiple scattering

Longitudinal emittance growth

Straggling ⇒ Muons fall out of RF bucket

- **MuScat: Determine shape of tails of multiple Coulomb scattering**

  → **Precise determination of heating term**

- **Required:**

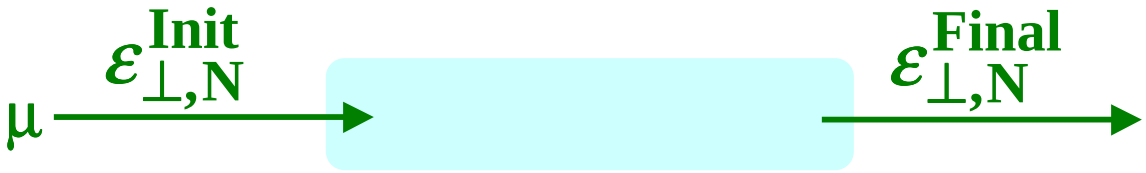
  → **Demonstration of principle of cooling**

  → **Measurement effect of straggling**

  → **Upgrade of MuScat**

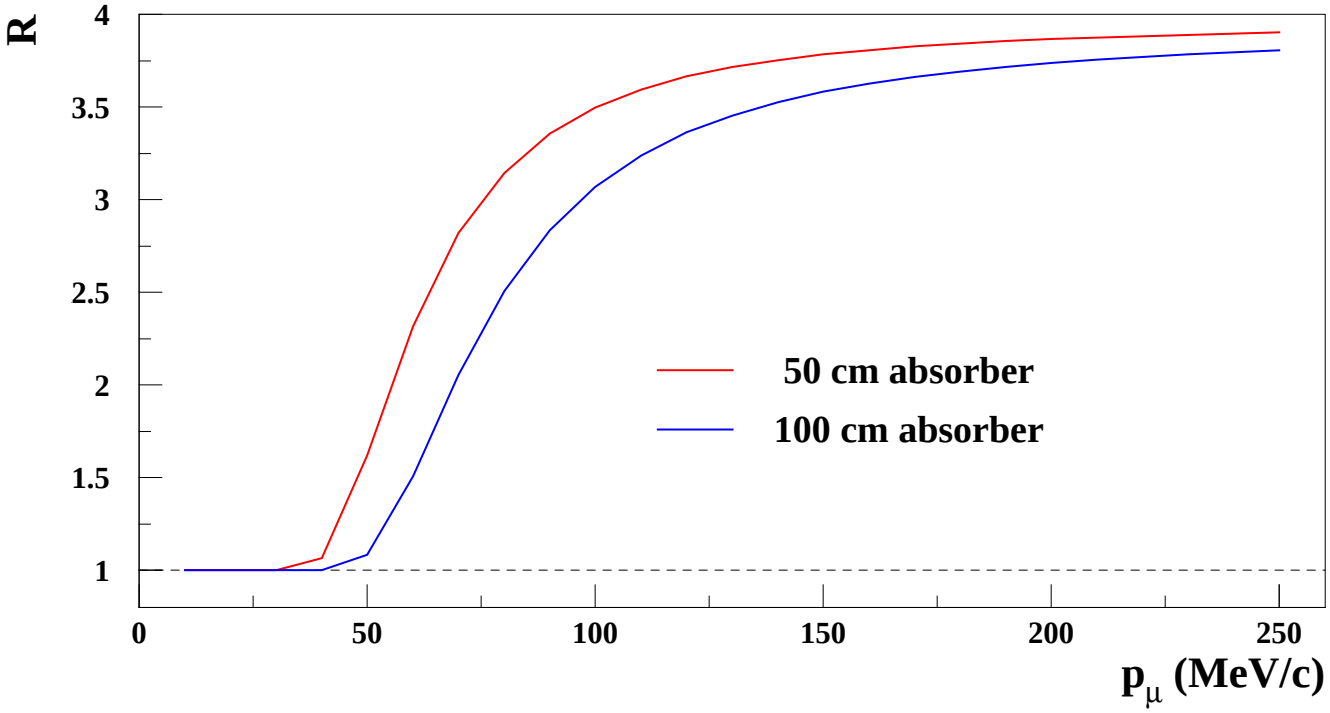
- Case study:

- **50 cm liquid hydrogen absorber**



- **Assume ratio of initial emittance to minimum emittance is 4 and calculate *R***

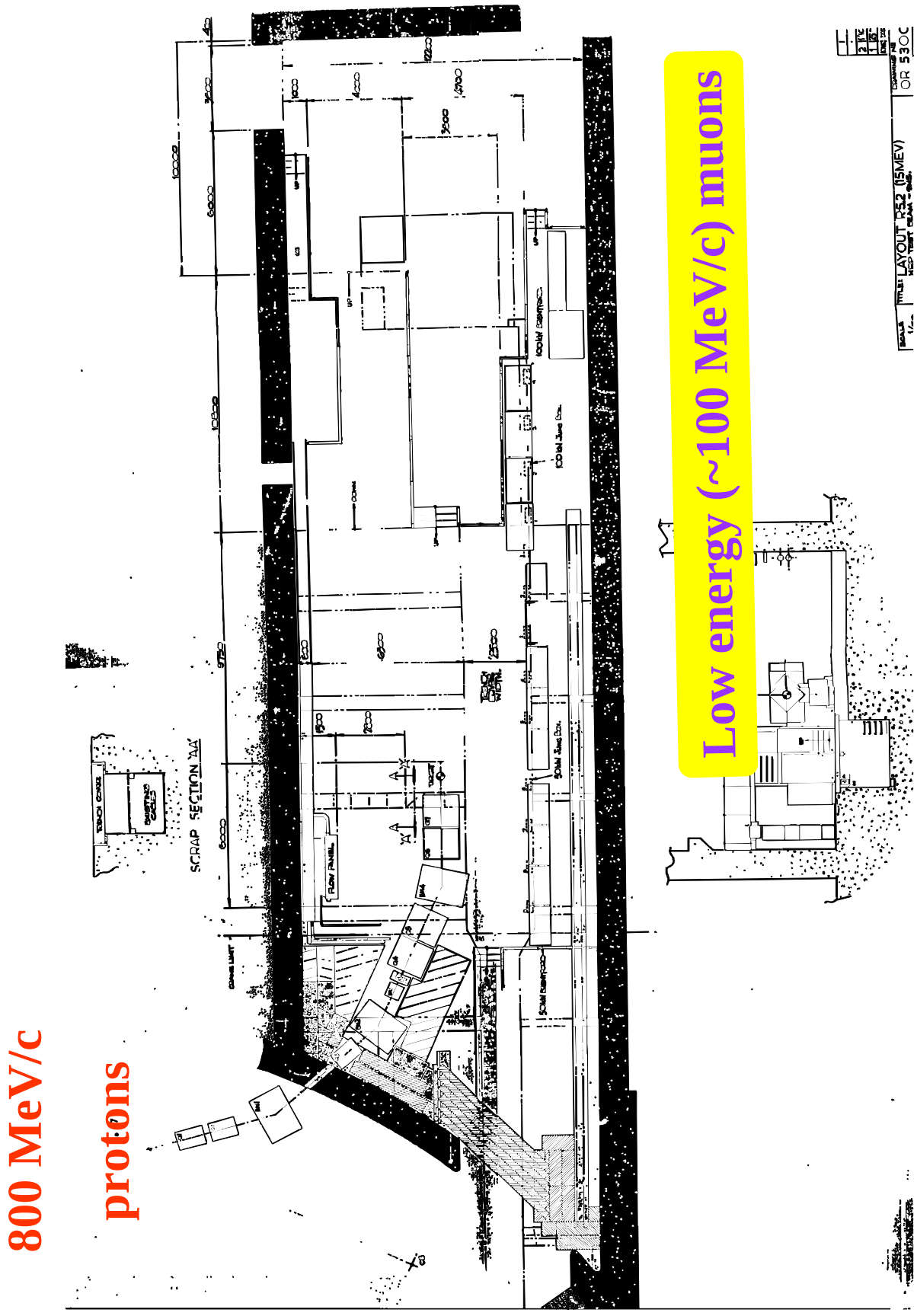
$$R = \frac{\varepsilon_{\perp,N}^{Final}}{\varepsilon_{\perp,N}^{min}}$$



⇒ **Use muon beam of 75 - 100 MeV/c momentum**

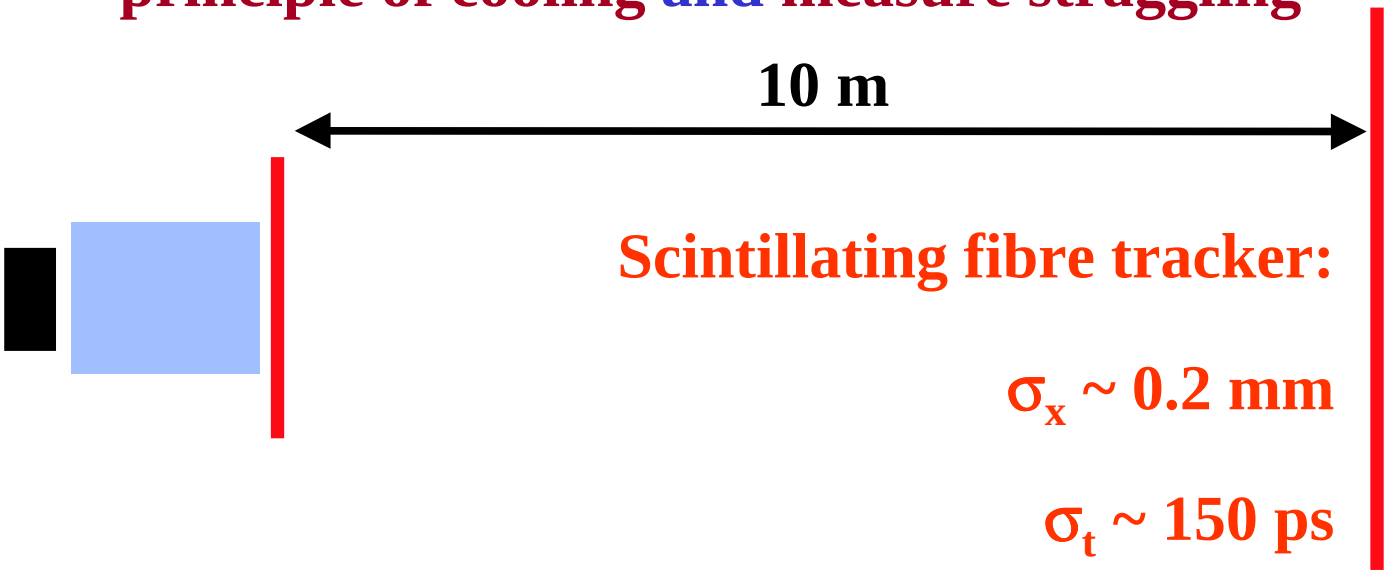
Phase I: Basic Physics of Ionisation Cooling

- Muons in HEP Test beam:



Phase I: Basic Physics of Ionisation Cooling

Possible layout for experiment to demonstrate principle of cooling and measure straggling



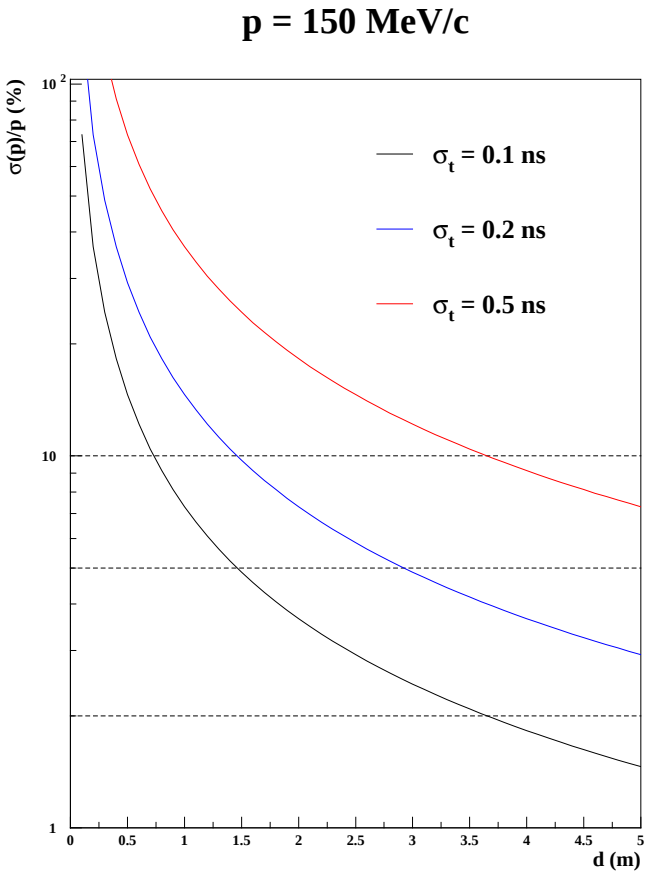
- Position and momentum measurement:

Require to reconstruct

$$m_\mu^2 c^2 \varepsilon_{\perp,\mathrm{N}}^2 = \left\langle x^2 \right\rangle \left\langle p_x^2 \right\rangle - \left\langle x p_x \right\rangle^2$$

before and after the absorber

- **Position and timing from scintillating fibre tracking detectors**

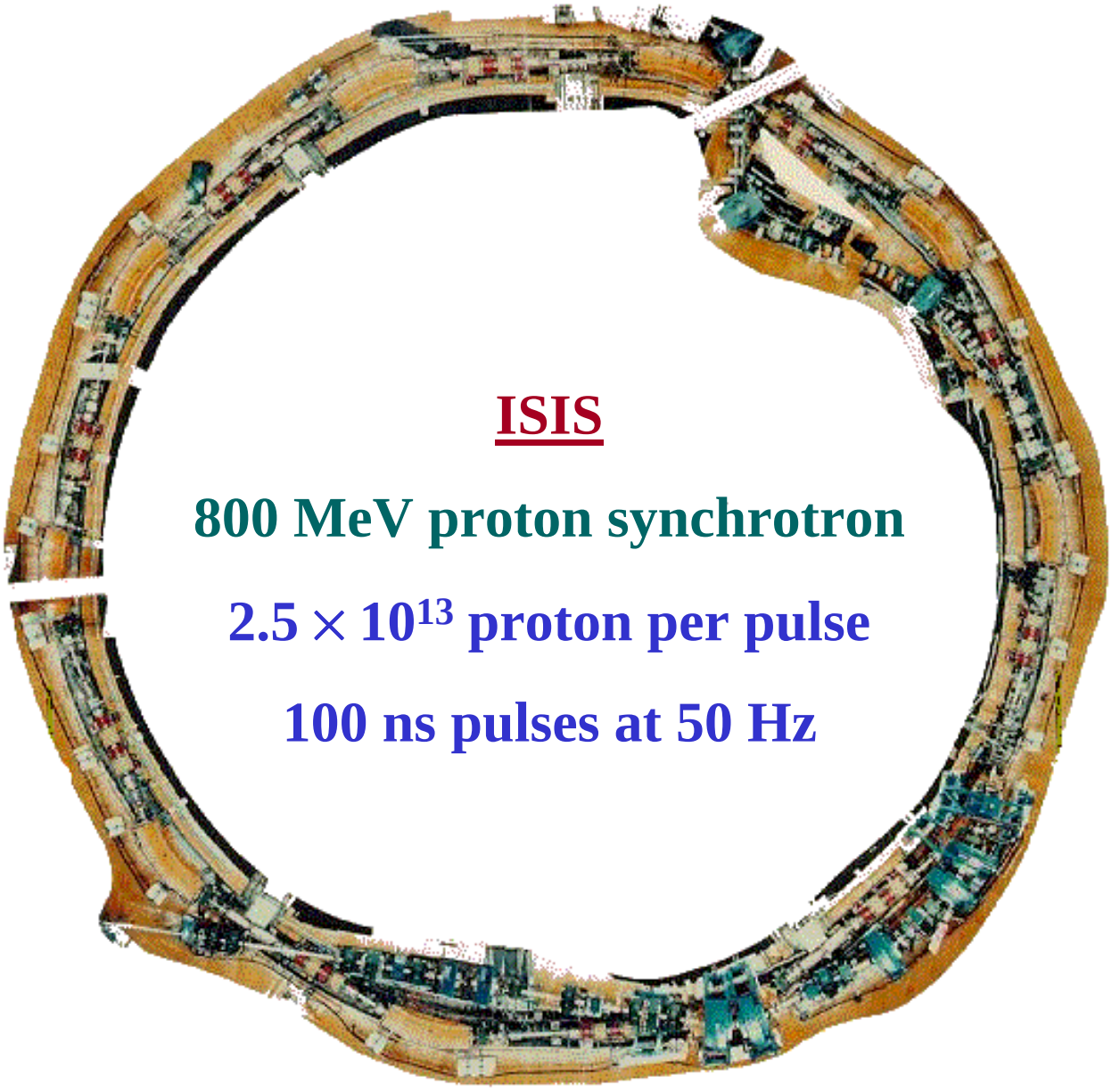


$$\frac{\sigma_{\varepsilon_{\perp,\mathrm{N}}}}{\varepsilon_{\perp,\mathrm{N}}} < 1\%$$

Demonstration of principle of cooling looks feasible with such a set-up

Muon beams for νFct R&D at ISIS

Phase II: A High Intensity Muon Beam



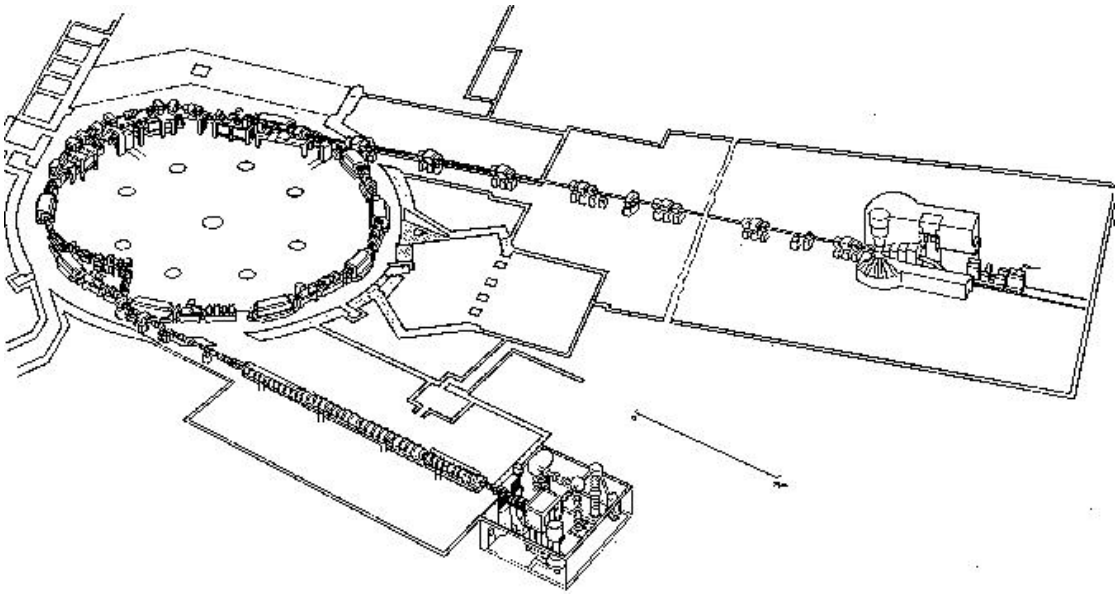
ISIS

800 MeV proton synchrotron

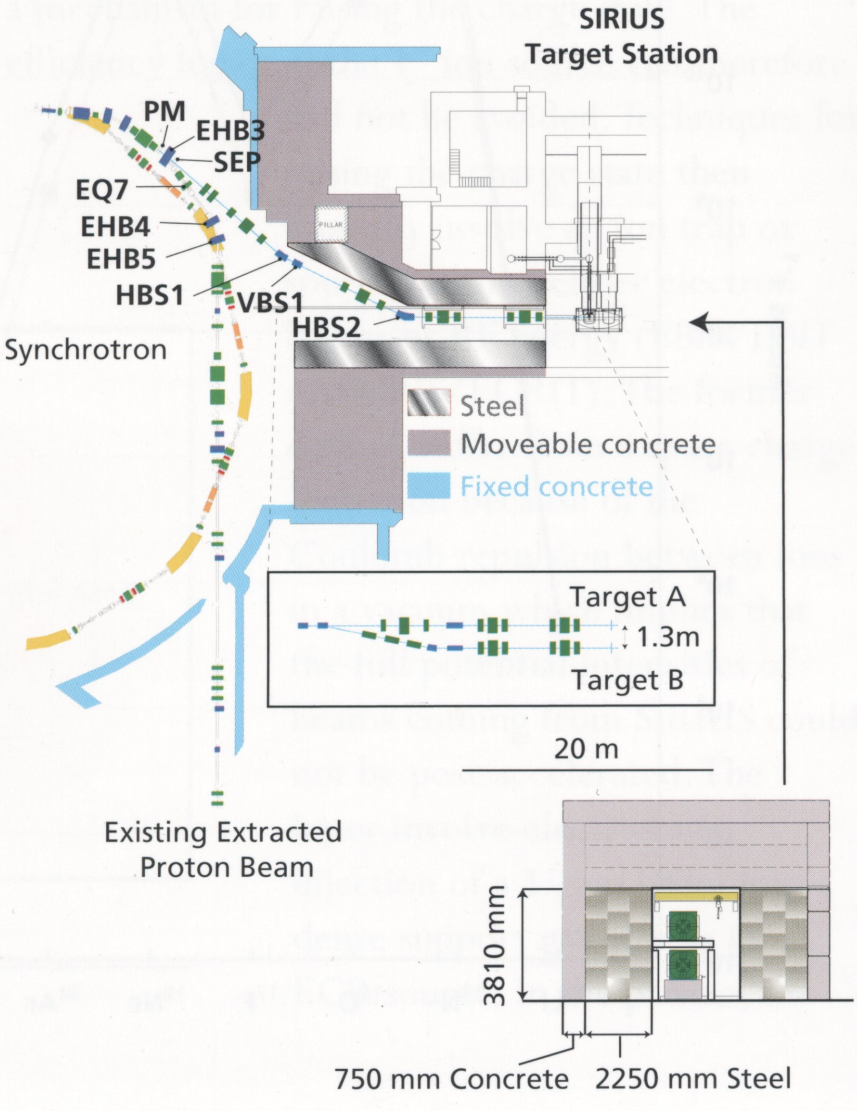
2.5×10^{13} proton per pulse

100 ns pulses at 50 Hz

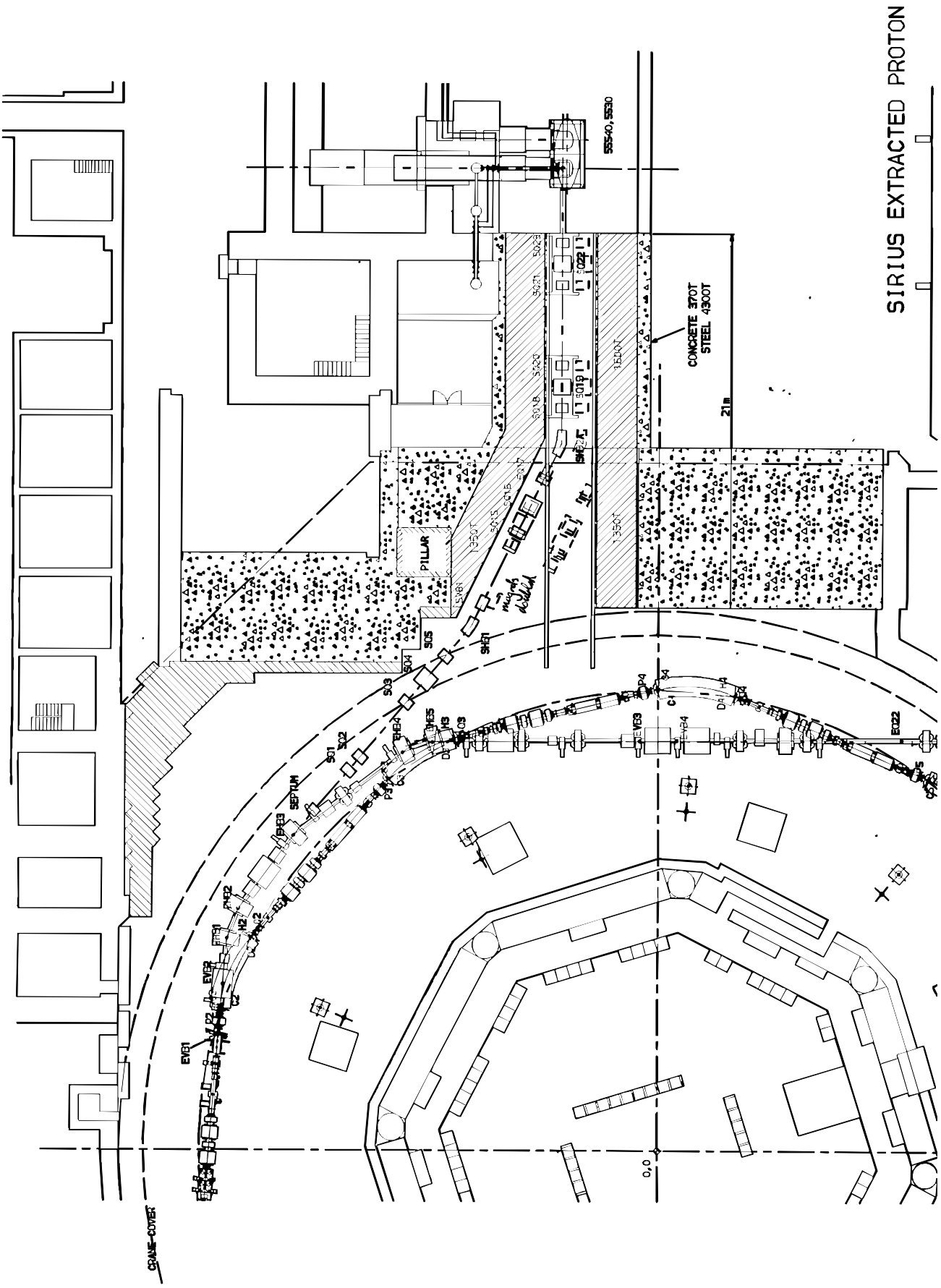
Phase II: A High Intensity Muon Beam



0.4154 m upstream of its nominal position.



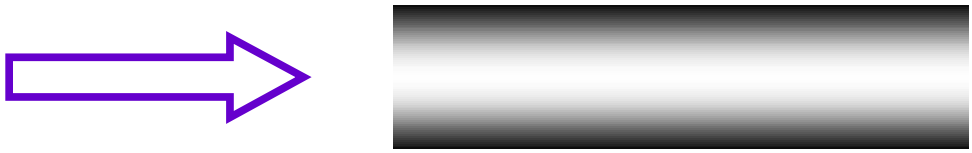
Phase II: A High Intensity Muon Beam



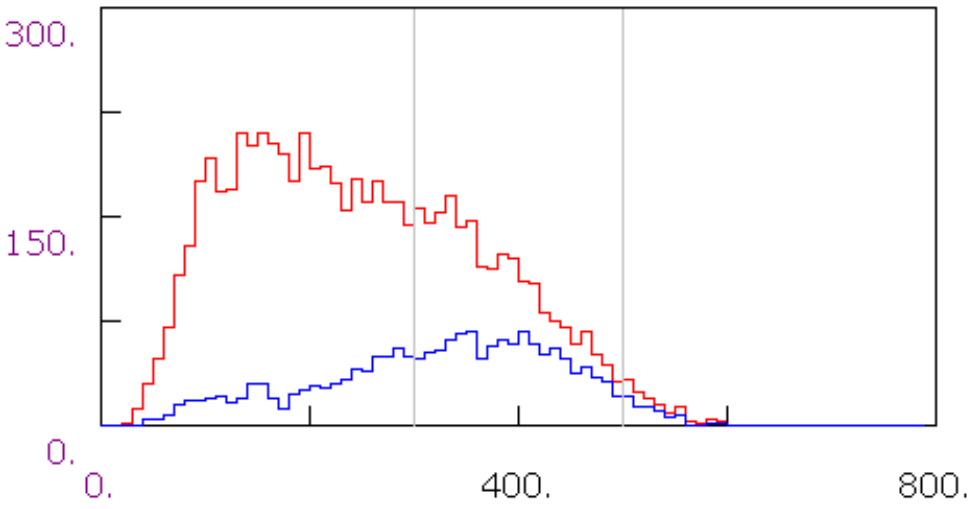
Pions at ISIS

ISIS

- **800 MeV Protons from ISIS**
- **2.5×10^{13} protons per pulse at 1 Hz (i.e. one bunch in 50)**
- **2 cm $\varnothing \times 5$ cm long Graphite Target**



- **~25 π^+/1000 protons $\Rightarrow 6 \times 10^{11}$ π^+ per pulse**
- **Capture ~20% $\Rightarrow 1 \times 10^{11}$ π^+ per pulse**



- **~12% inside ±25% momentum byte $\Rightarrow 10^{10}$ π^+ per pulse**

P. Drumm

Muons at ISIS - first ideas:

- **Decay/muon capture channel not yet studied but perhaps possible to keep between 10% and 50% of the muons:**

  $\Rightarrow$ ~ 10^9 muons in 100 ns bunch

- **Tight bunching possible by lowering RF field early in acceleration cycle. Technique to be simulated in tracking calculations and tested in machine development period soon.**

  $\Rightarrow$ Keep ~ 1% of muons if make a 10 ns bunch

  $\Rightarrow$ ~ 10^7 muons in 10 ns bunch

- **Design study: Of proton beam line, target, decay channel as well as mini-bunching scheme now starting**

Possible route to high intensity muon beam

Summary

"Prospects for a High Intensity Muon Facility in the UK"

Good!

Phase I: Basic Physics

- MuScat has made excellent start in measurement of 'basic physics' parameters of the ionisation cooling channel
- Need to develop MuScat to look at *dE/dx*, straggling and demonstration of the principle of cooling (perhaps in HEP Test Beam at RAL)

Phase II: High Intensity Muon Facility

- ISIS offers possibility to develop an intense bunched muon beam
- Need to develop ideas for provision of beam in parallel to ideas for targetry, capture and instrumention
- Possibility to build towards an engineering demonstration of ionisation cooling